

# Ionospheric Corrections to Tropospheric Retrievals

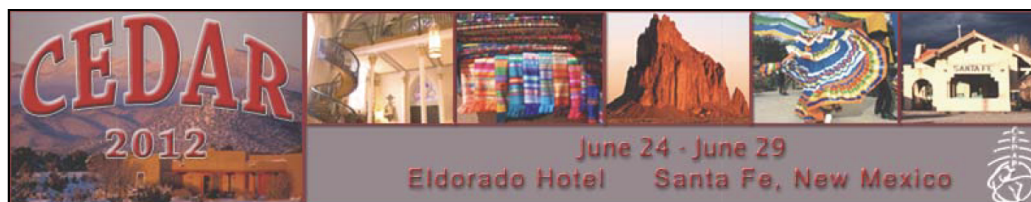
**A. J. Mannucci**

**C. O. Ao**

**B. A. Iijima**

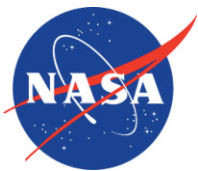
**Xiaoqing Pi**

*Jet Propulsion Laboratory, California Institute of Technology*



Technique and Applications of Radio Occultation Workshop

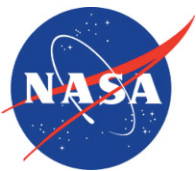
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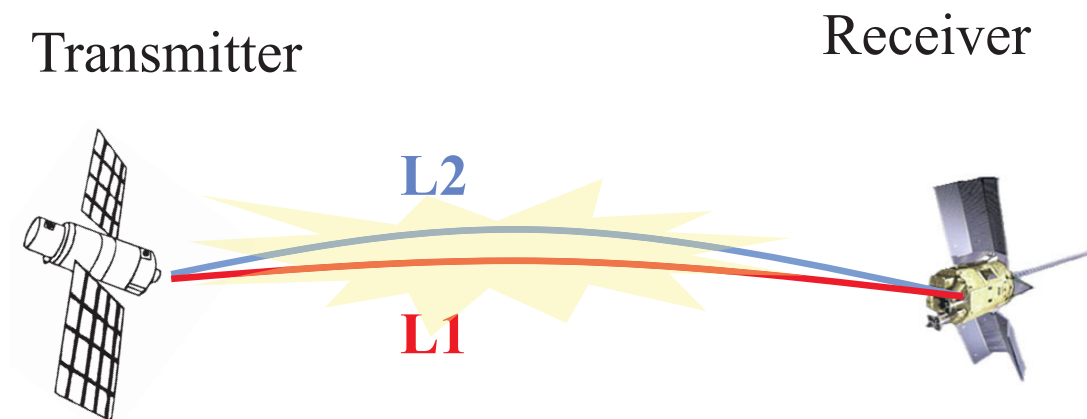
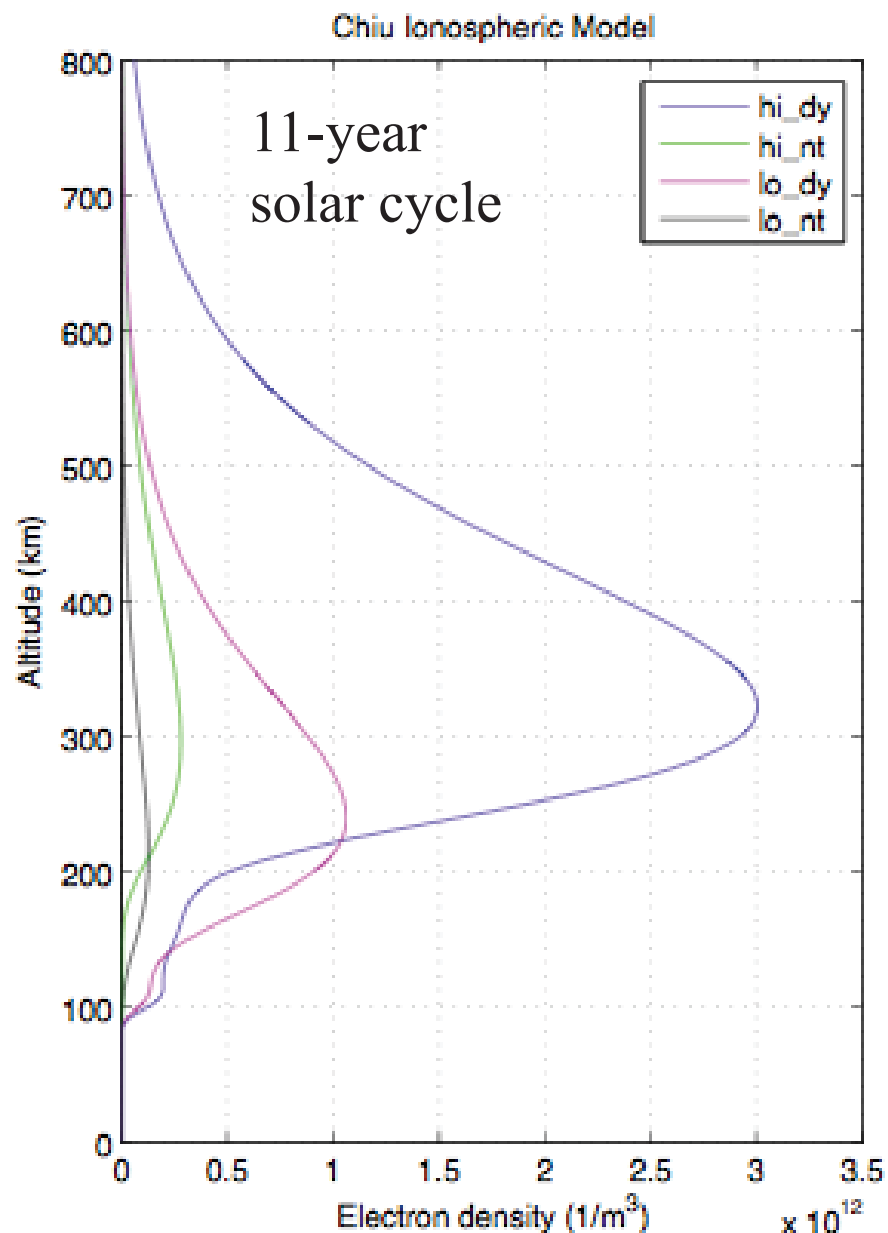
# Topics

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- **Ionospheric Correction**
- **Impacts: large scale structure**
- **Impacts: small scale structure**
  
- **Goals for CLARREO mission (climate data records)**
  - **Fractional refractivity accuracy  $\sim 0.03\%$**
  - **Temperature accuracy  $\sim 0.05\text{K}$**



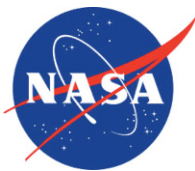
# Ionospheric Residual Error



$$L_3 = \frac{1}{f_1^2 - f_2^2} (f_1^2 L_1 - f_2^2 L_2)$$

“Ionosphere-free” linear combination

Note: no assumptions made about ionospheric structure



# Bending Angle Correction

- Assumes linear relation between bending angle and refractive index
  - Refractive index  $\sim 1/f^2$
- Residual error due to non-linearity

**Eq. (1)**  
**Bending angle correction**

$$\alpha_c(a) = \left[ \frac{f_1^2}{f_1^2 - f_2^2} \right] \alpha_1(a) - \left[ \frac{f_2^2}{f_1^2 - f_2^2} \right] \alpha_2(a)$$

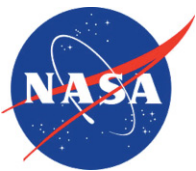
**Eq. (2)**  
**Residual error in bending**

$$\Delta\alpha(a) = \frac{C^2}{f_1^2 f_2^2} a \frac{d^2}{da^2} \int_a^\infty \frac{x N_e^2 dx}{\sqrt{x^2 - a^2}}$$

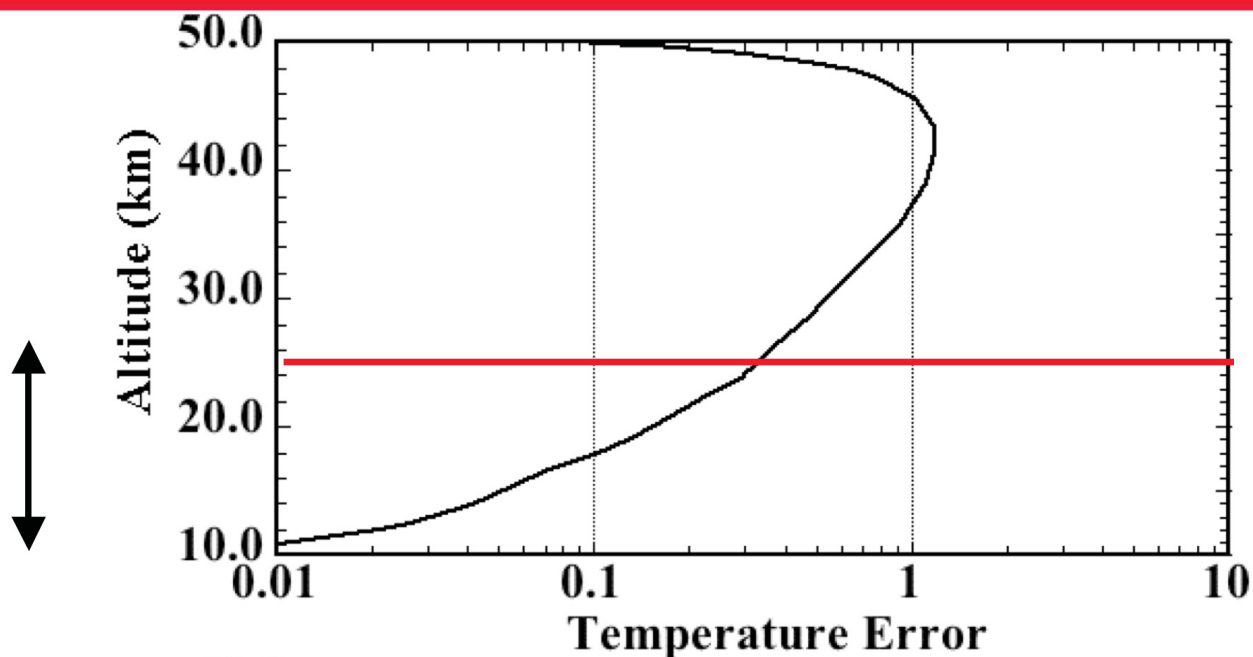
**Eq. (3)**  
**Residual error in refractivity**

$$\Delta N = \frac{10^6}{\pi} \int_a^\infty \frac{\Delta\alpha(x) dx}{\sqrt{x^2 - a^2}}$$

See Syndergaard, Radio Science, 2000

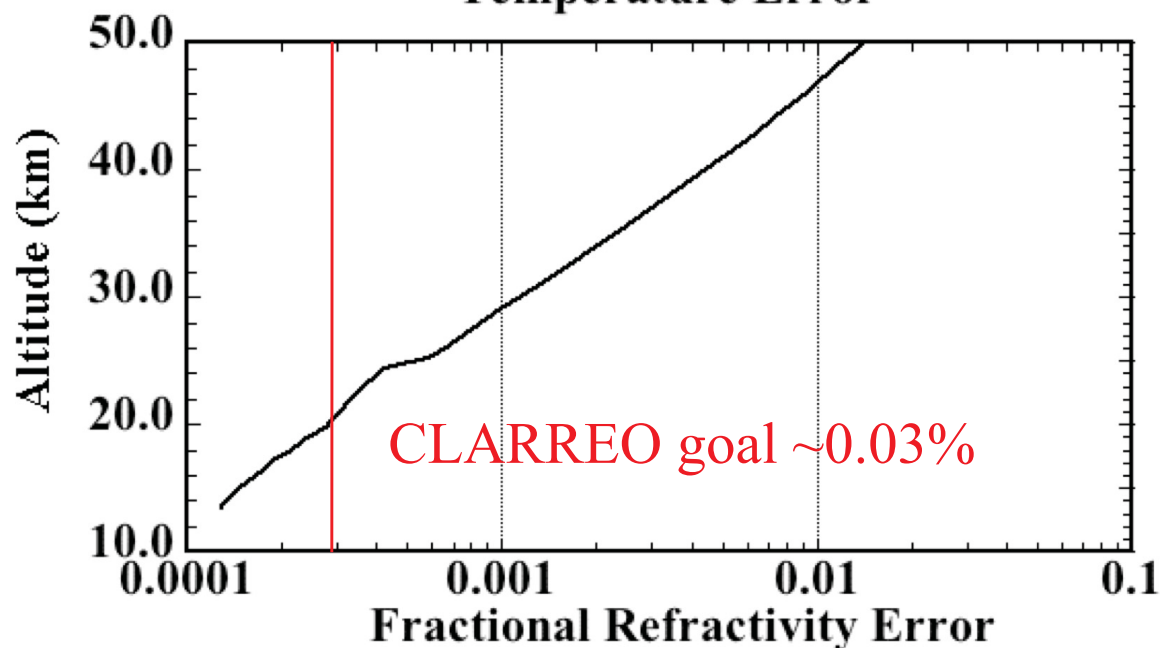


# Magnitude Of The Error



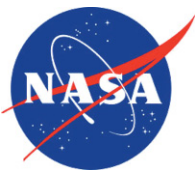
Method: ray-trace signal through a model ionosphere

From the solar maximum simulation of Kursinski et al. JGR, 1997

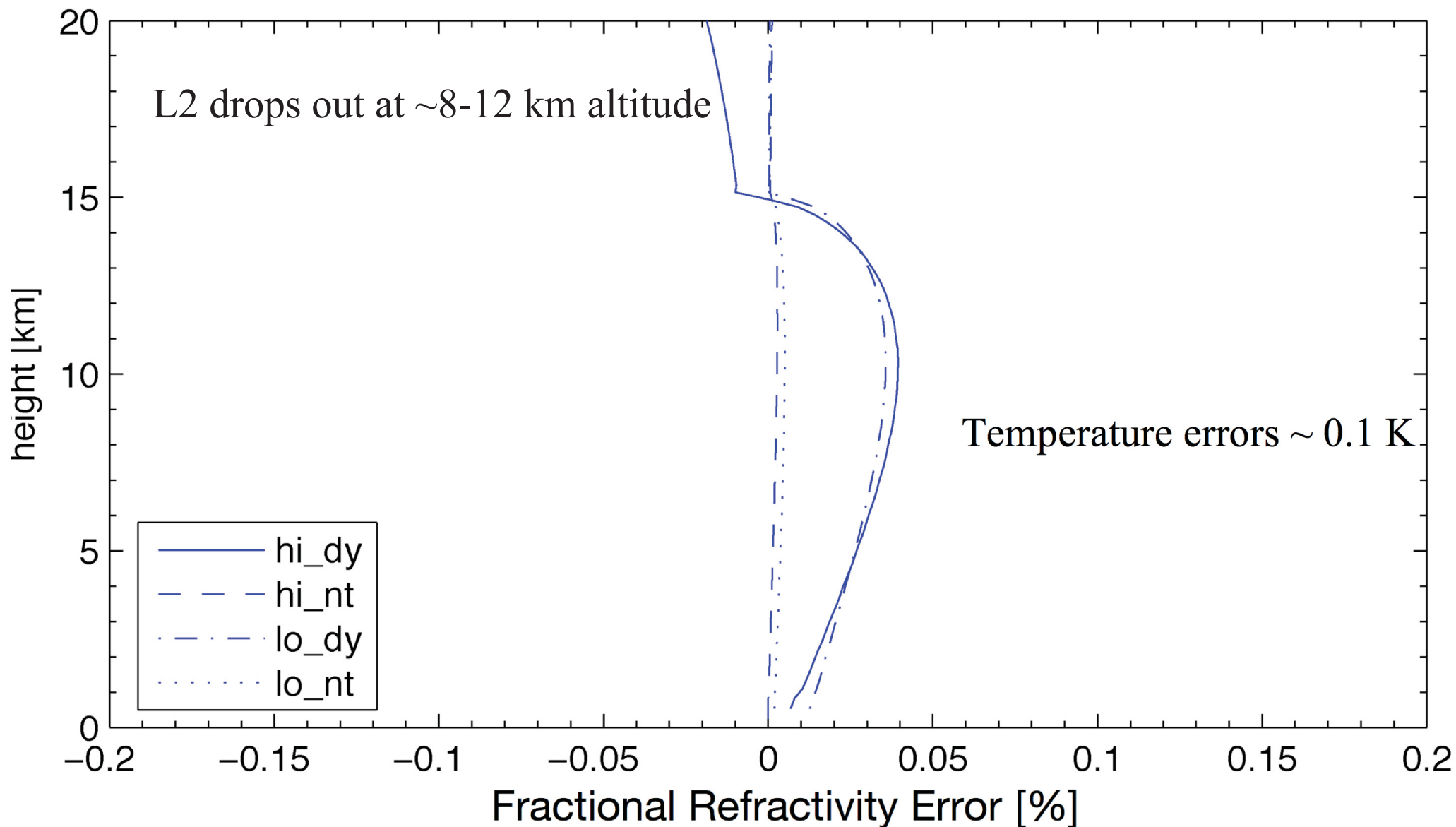


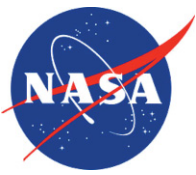
Below 10 km, iono errors remain negligible

*Error is too large by factor of 2-3*



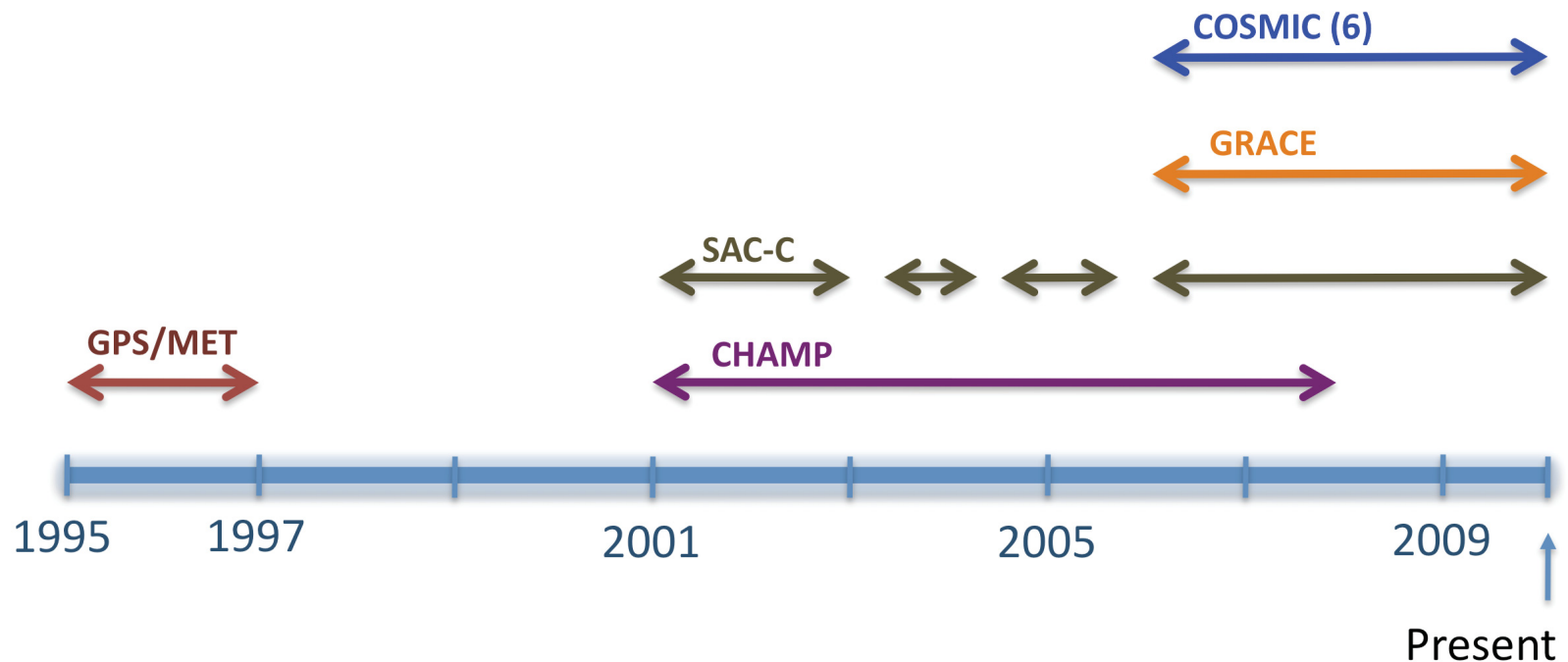
# Impact of L2 Loss: Simulation Study

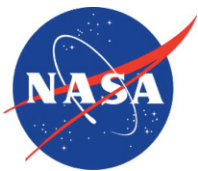




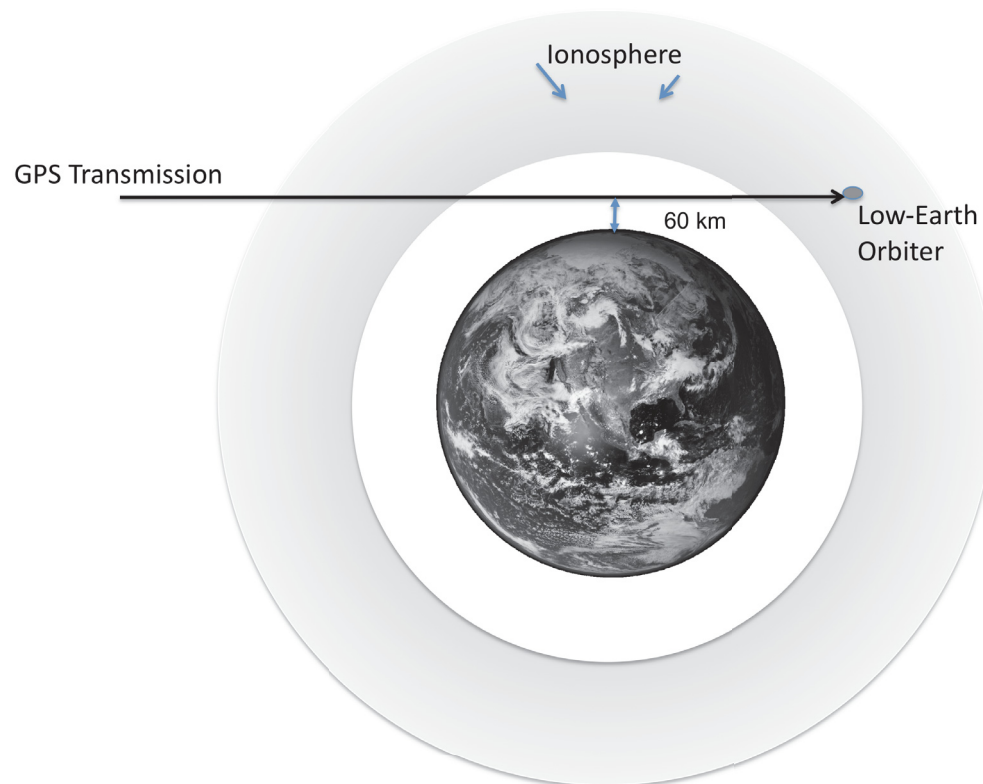
# Detailed Ray Tracing Study – Large Scale Structure

- Separately ray-trace L1 and L2 signals through simulated ionospheres (IRI and JPL-GAIM)
- Assess magnitude of residual error due to ray-path separation and “higher-order” terms
- Assess impact of S/C altitude
  - Including  $n=1$  assumption at S/C (not shown)

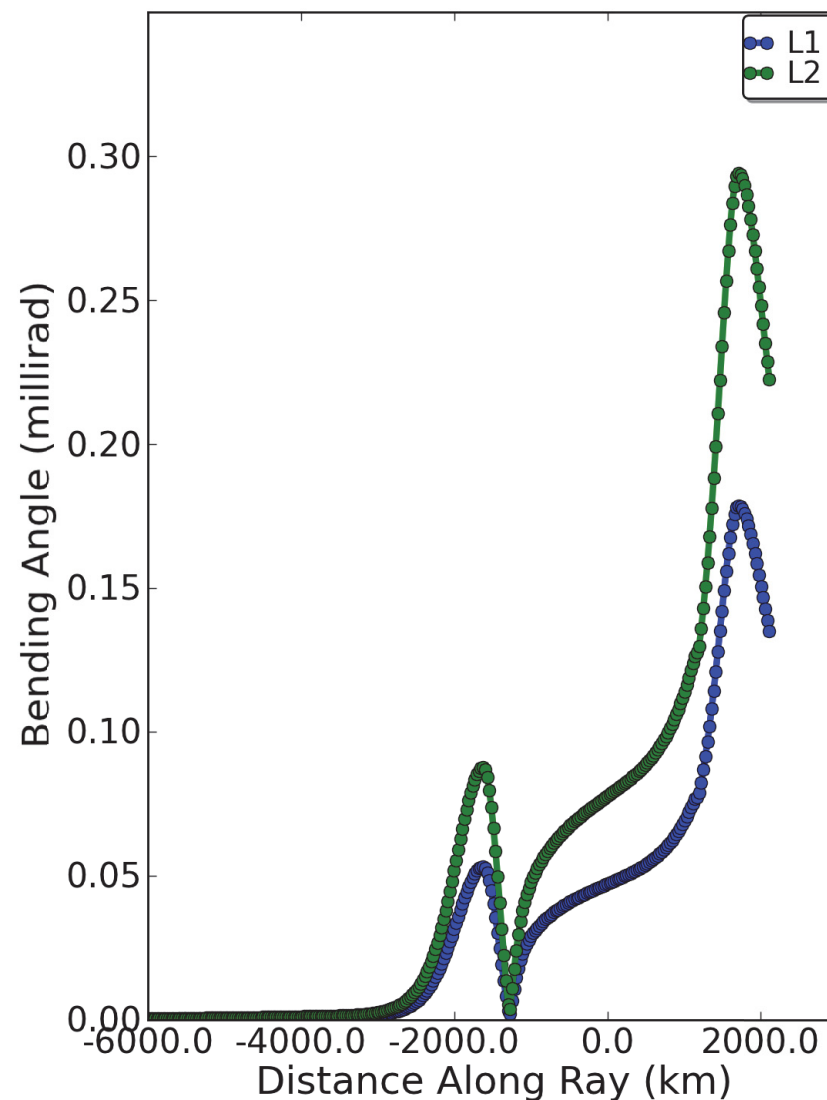




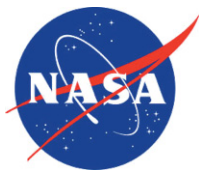
# Raypath Geometry and Bending Angle



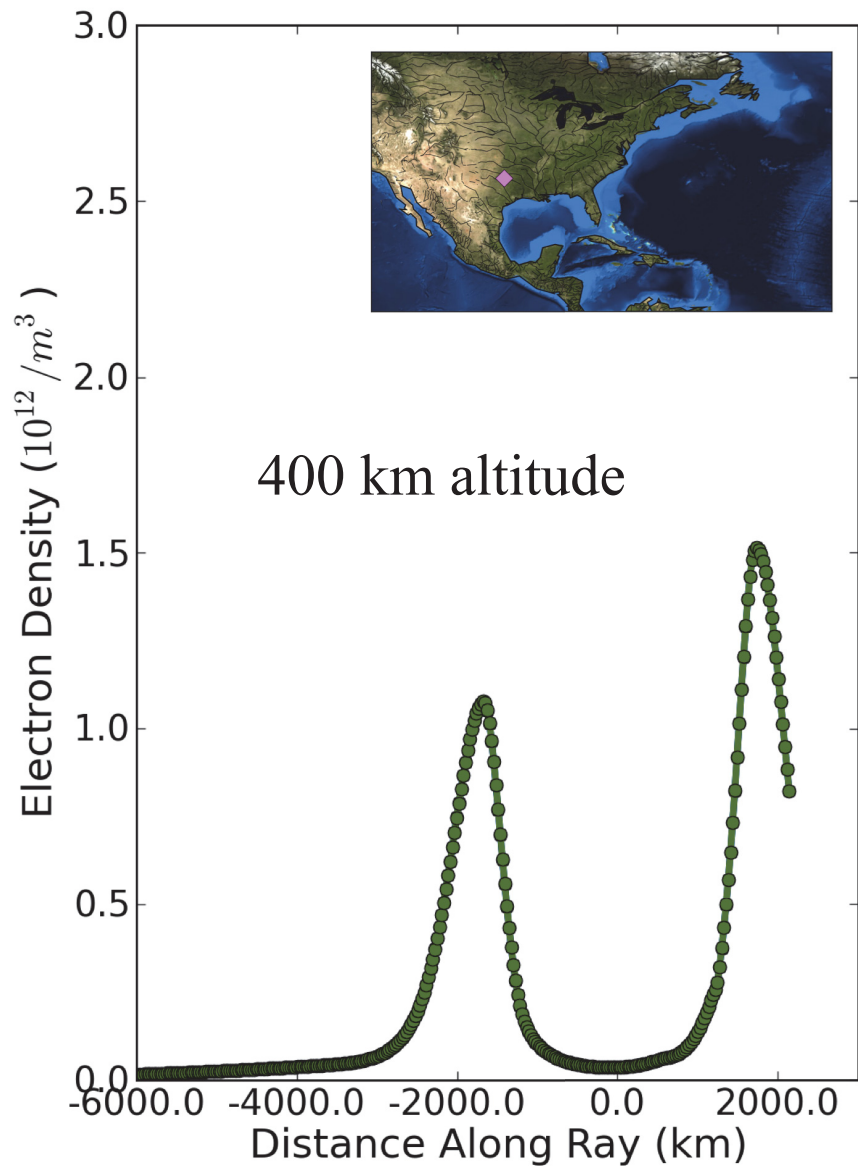
400 km altitude  
(CHAMP)



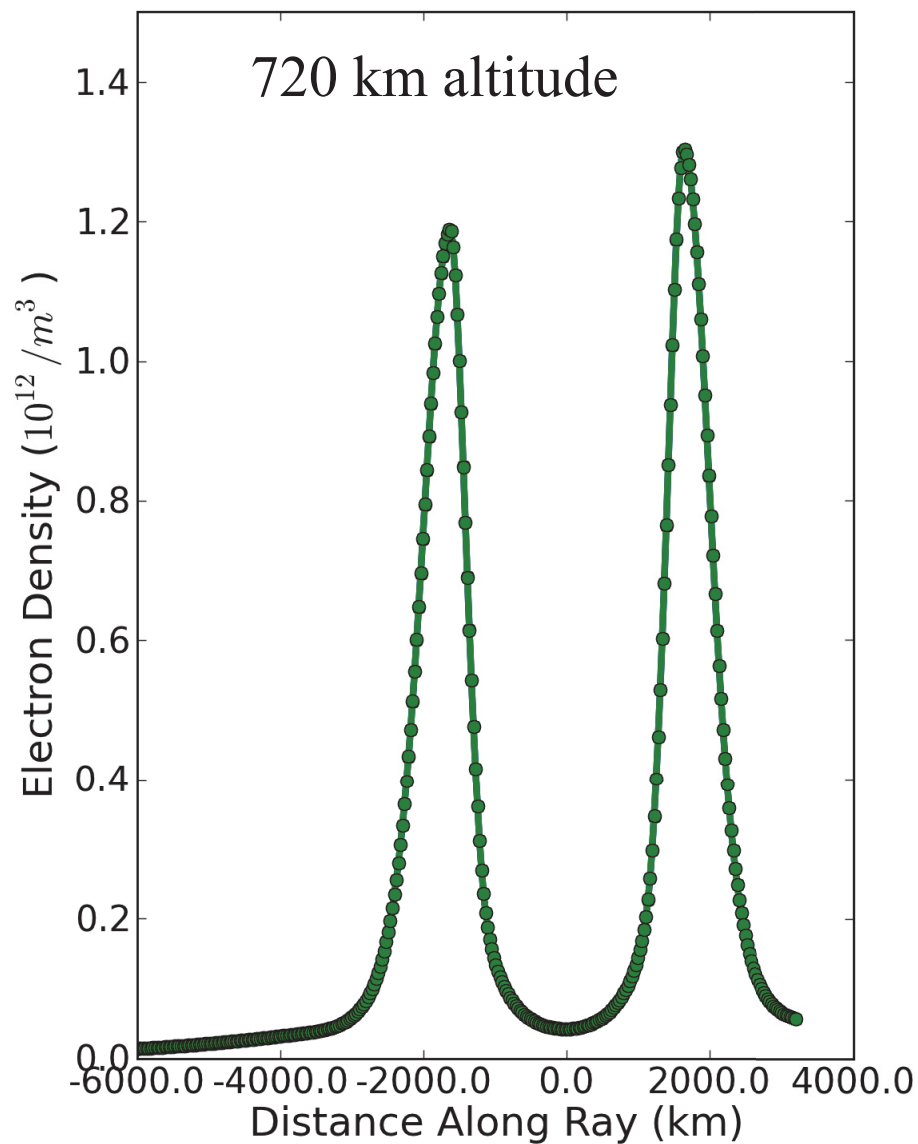
Mannucci et al., *Atmos Meas Tech*, 2011



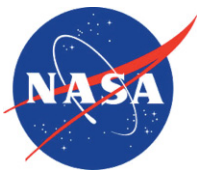
# CHAMP Versus COSMIC Altitudes



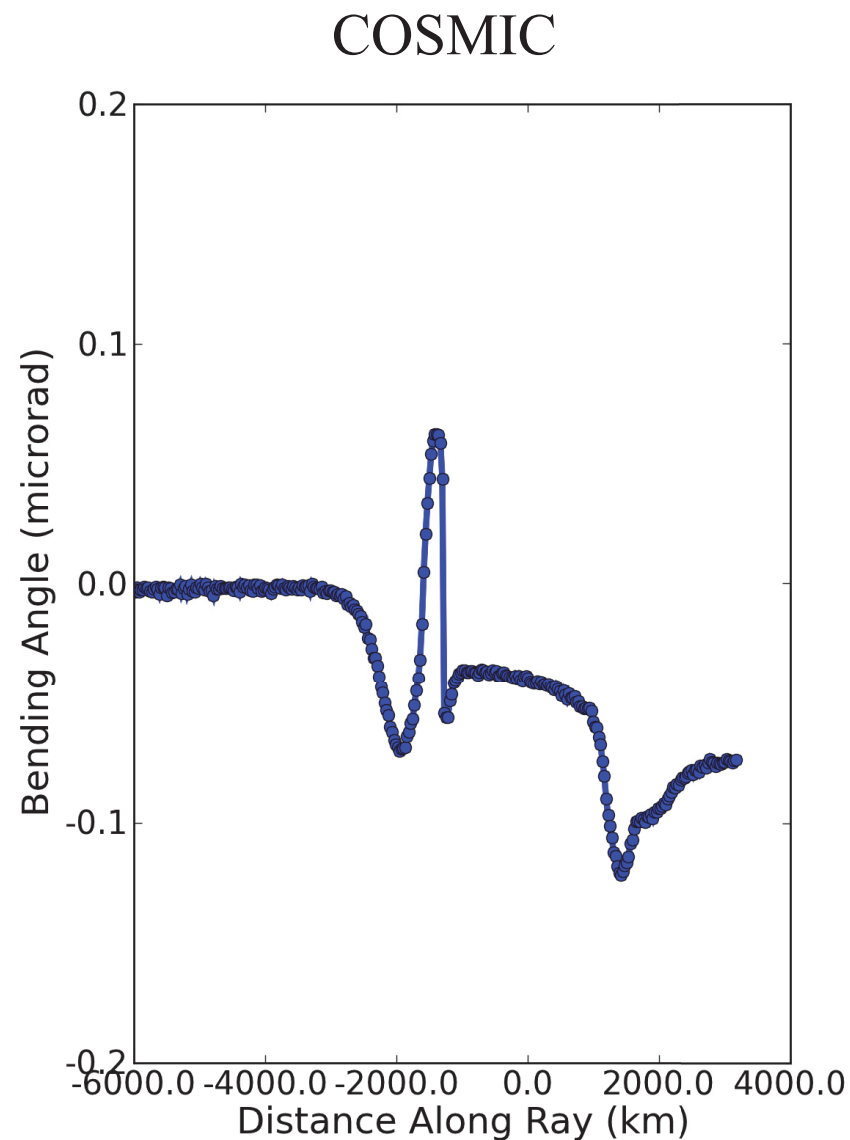
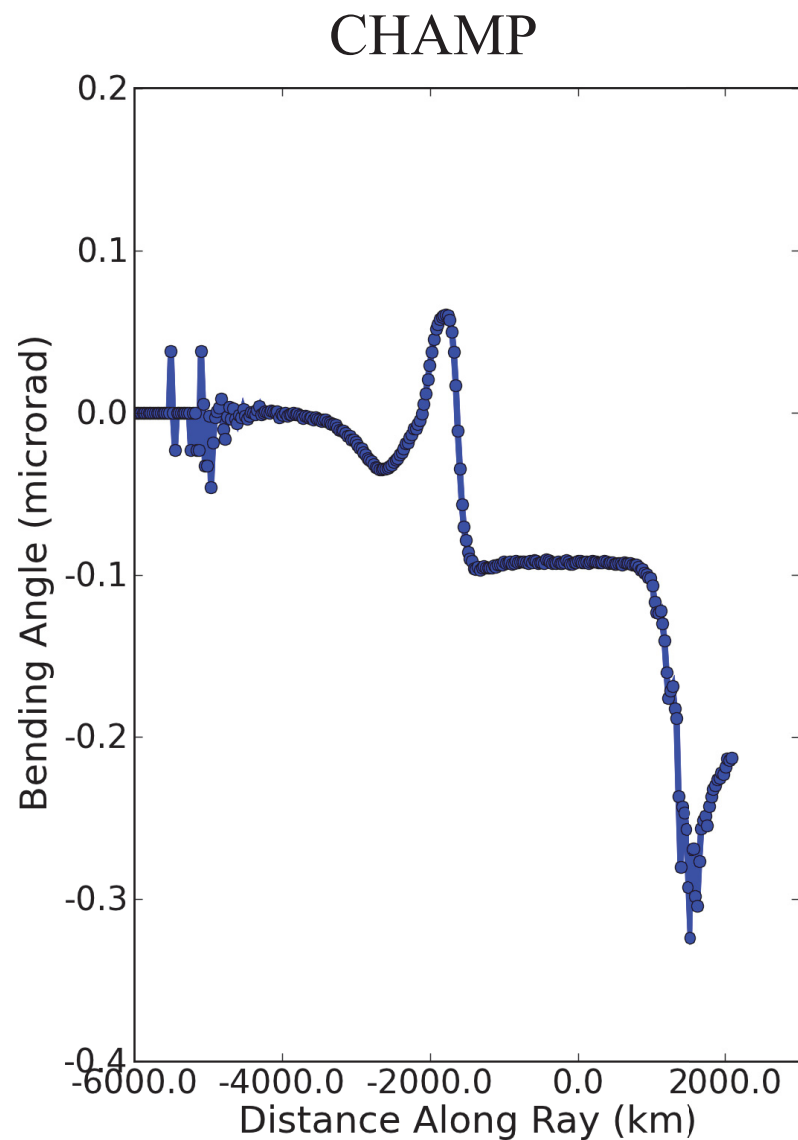
IRI, CHAMP geometry

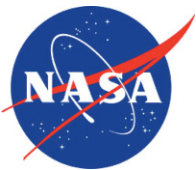


GAIM, COSMIC geometry

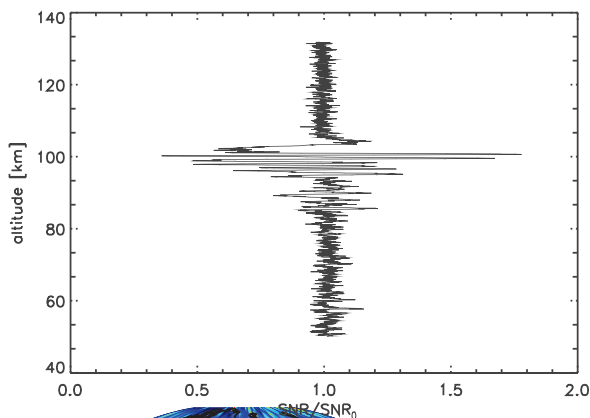


# Residual Bending Angle After Correction

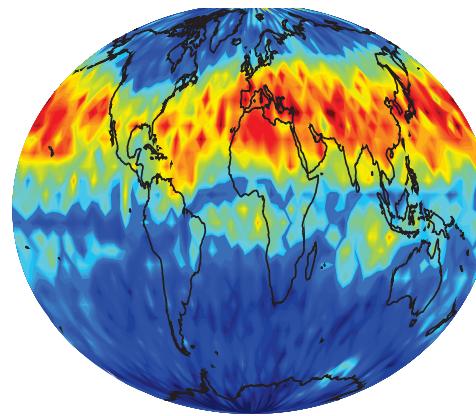
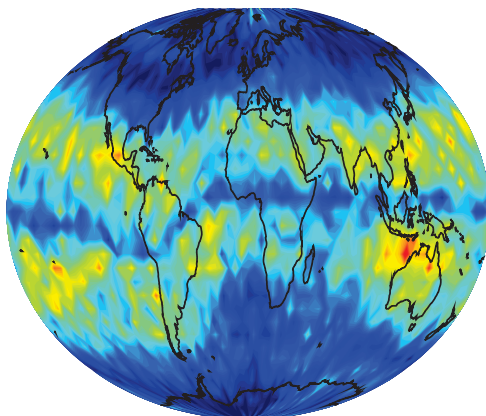
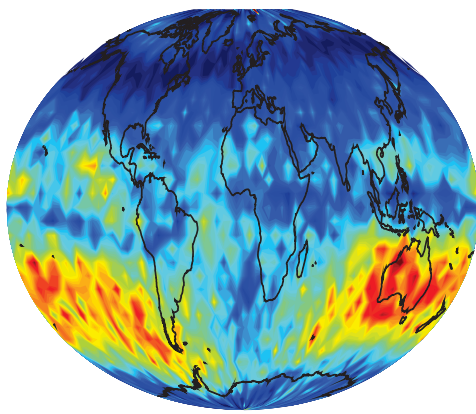
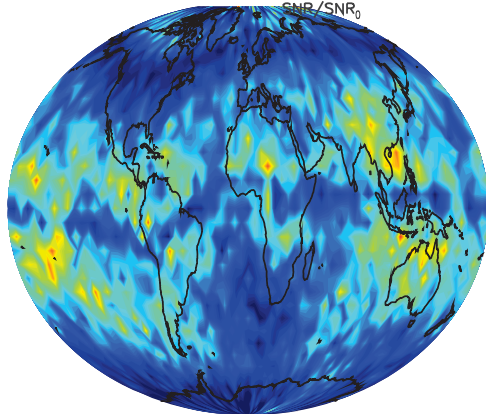




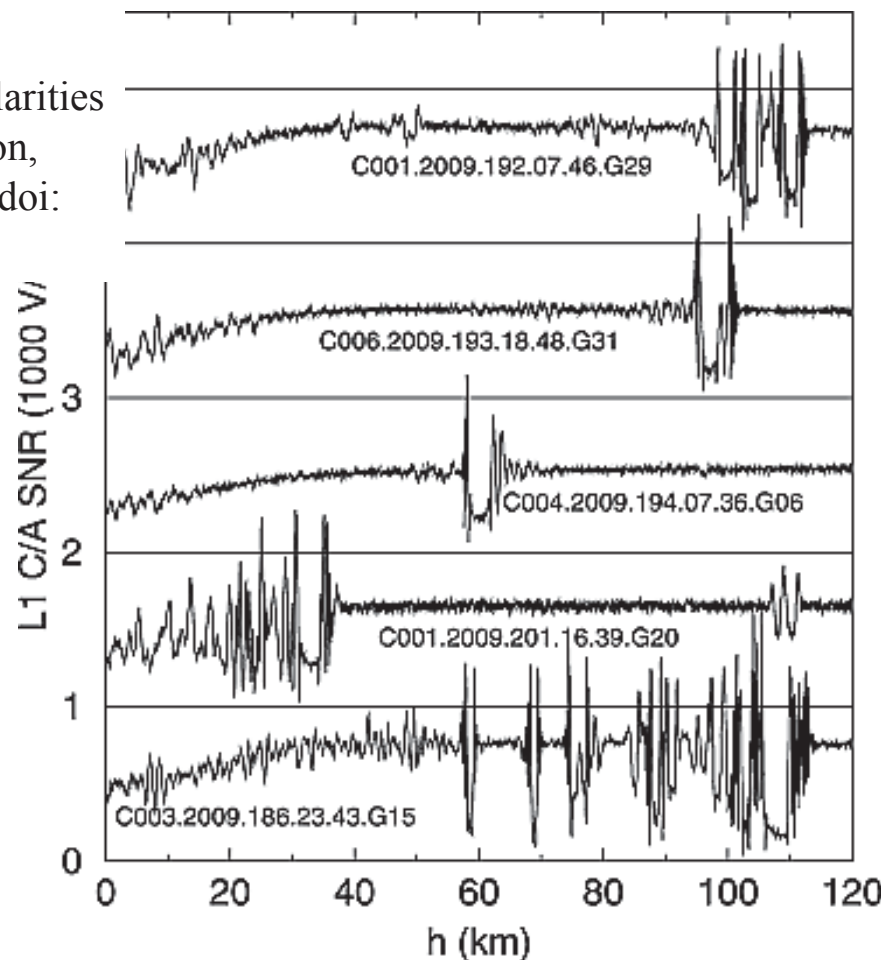
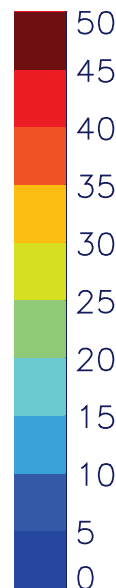
# Small Scale Structure *E*-Region



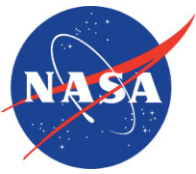
Arras, C., et al. (2008), A global climatology of ionospheric irregularities derived from GPS radio occultation, *Geophys. Res. Lett.*, 35, L14809, doi: 10.1029/2008GL034158.



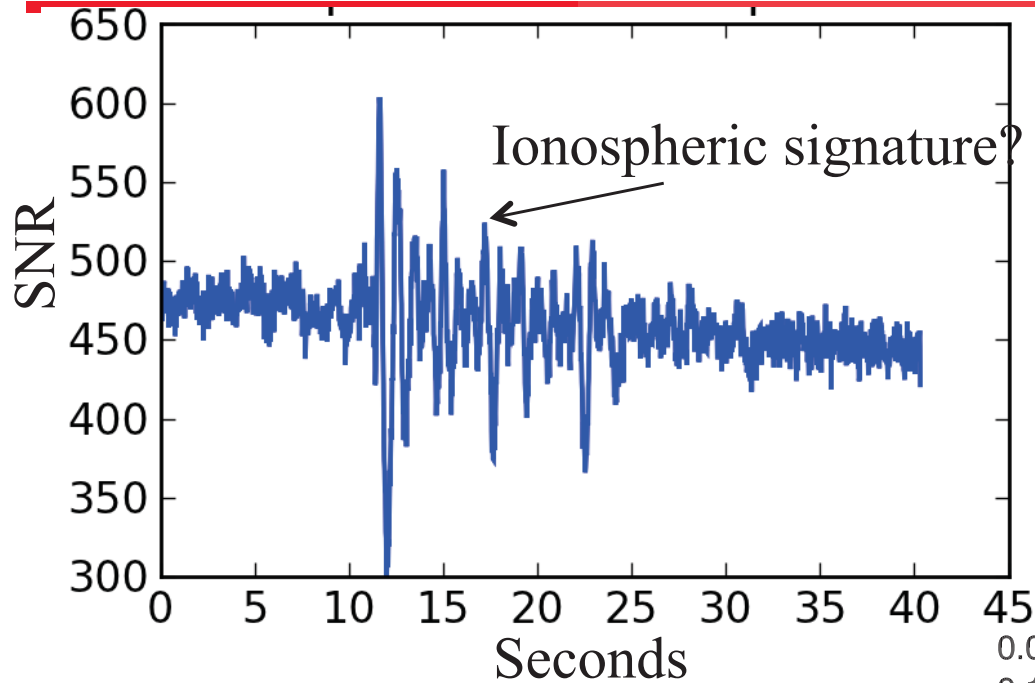
occurrence rate [%]



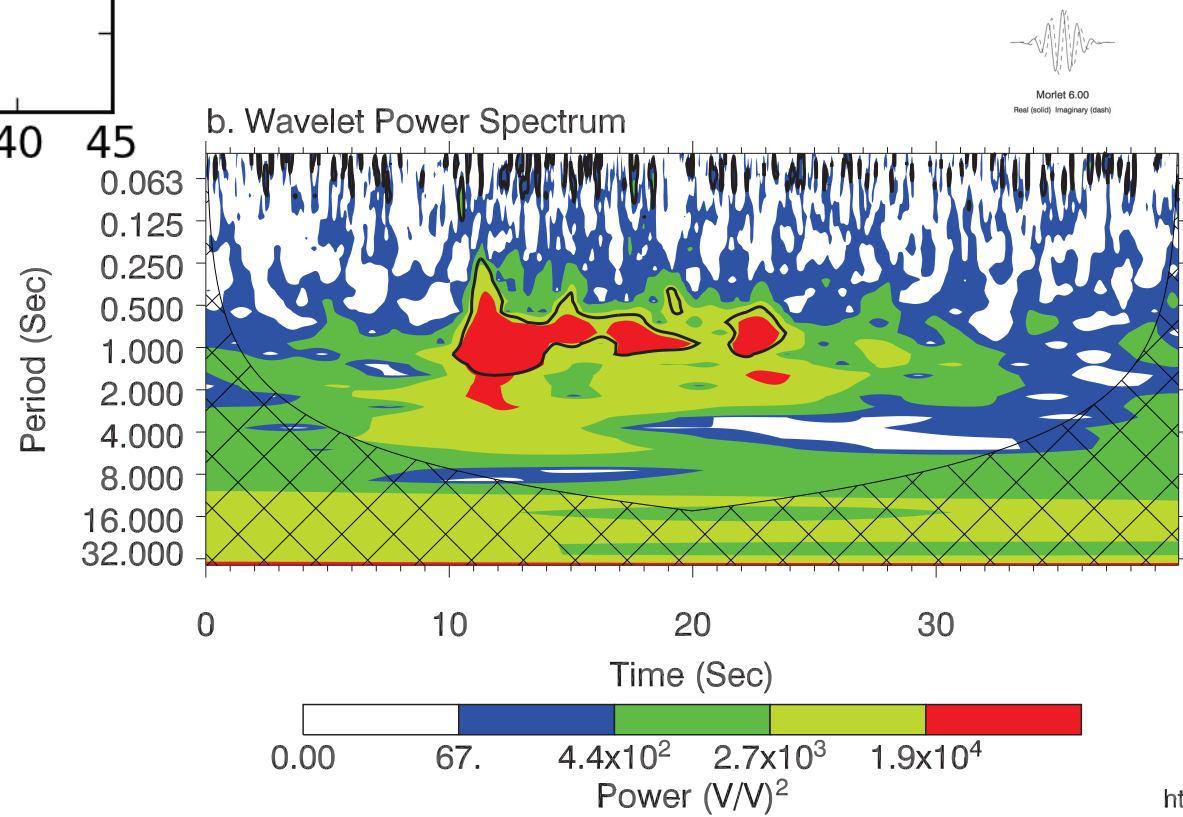
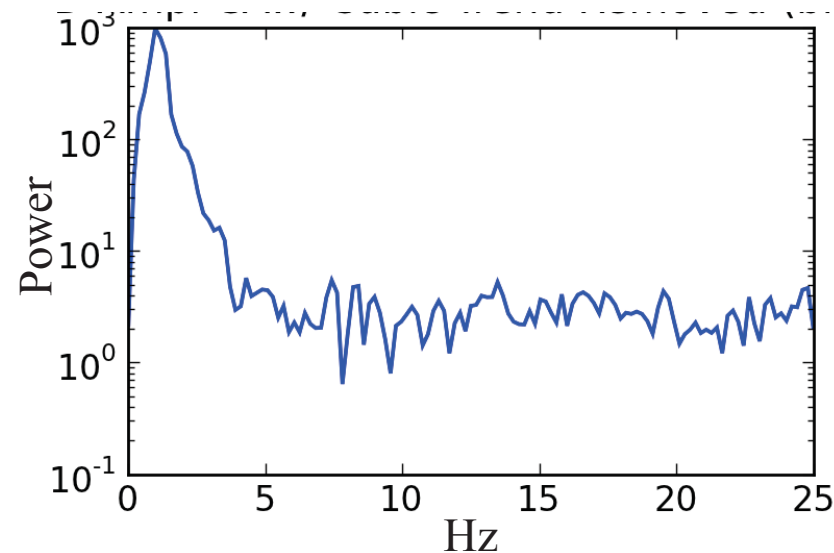
Zeng, Z., and S. Sokolovskiy (2010), Effect of sporadic E clouds on GPS radio occultation signals, *Geophys. Res. Lett.*, 37, L18817, doi: 10.1029/2010GL044561.



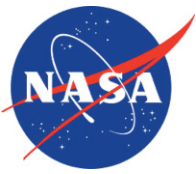
# Small Scale Structure & Data Characterization



- Data from 50-120 km altitude contains signatures of ionospheric structure – atmospheric structure is nearly absent



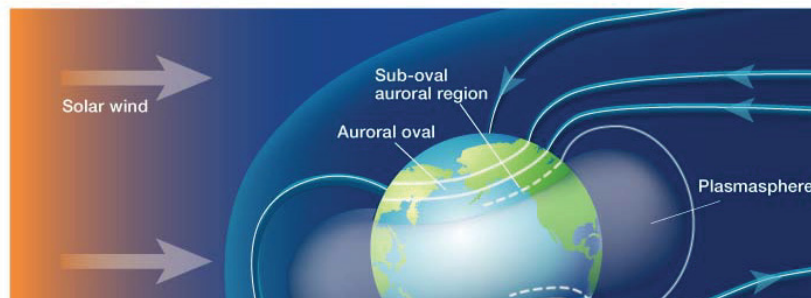
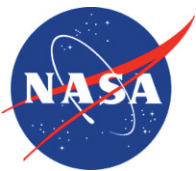
htt



# Summary

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- **Ionosphere affects radio occultations significantly, particularly at stratospheric altitudes**
- **Variations with solar and diurnal cycle are major concerns for observing climate trends**
- **Large scale and small scale ionospheric structure have different impacts**
- **The International Radio Occultation Working Group (CGMS) will benefit from greater participation of the ionospheric community**



## Earth-Sun System Exploration 5

January 13-19, 2013

Kona, Hawai'i

**“Earth Sun System Disturbances: Weak, Moderate, and Extreme”**

Convenors: Patrick T. Newell and Bruce Tsurutani

Program Committee

(Sun through ionosphere)

Kazunari Shibata, Kyoto University, Japan

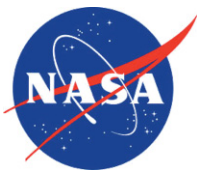
Roberto Bruno, Istituto Fisica Spazio Interplanetario, Italy

Larry Lyons, University of California, Los Angeles, USA

Tony Lui, JHU/Applied Physics Laboratory, USA

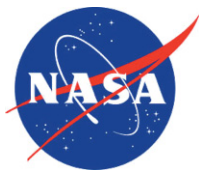
Jesper Gjerloev, University of Bergen, Norway

<http://sd-www.jhuapl.edu/Aurora/ESSE/index.html>

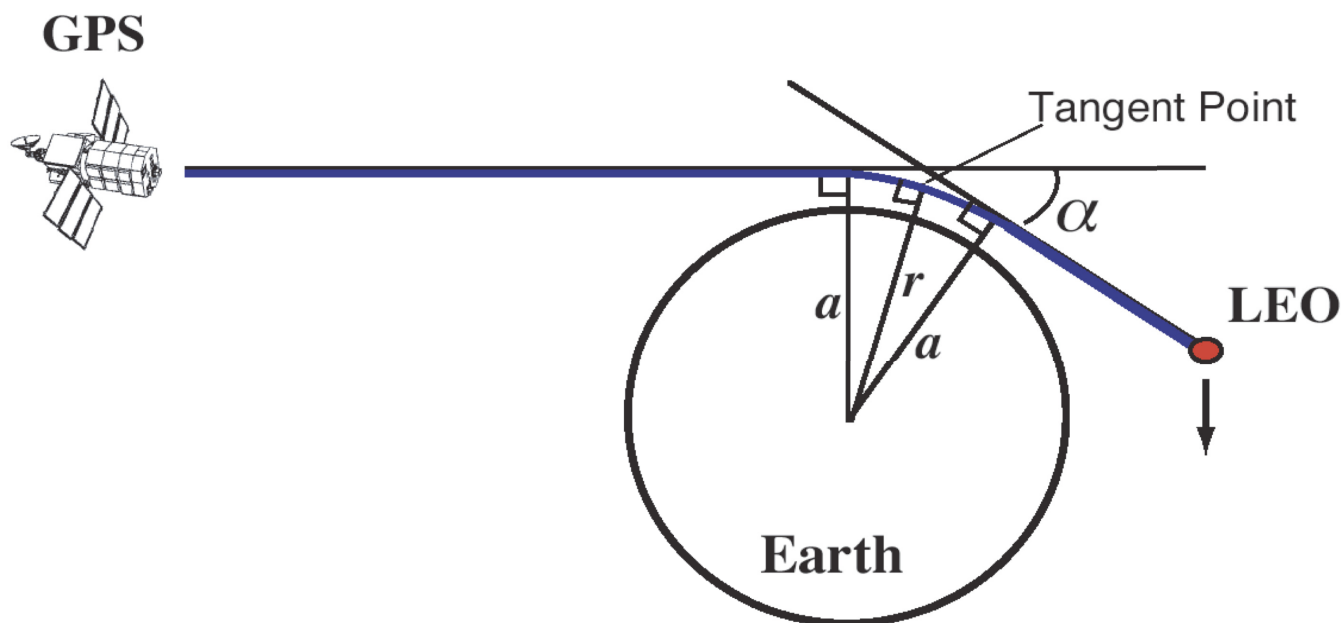


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# Backup Slides

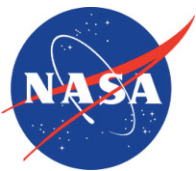


# Upper Altitude Extrapolation



$$\ln(n(a)) = \frac{1}{\pi} \int_a^{\infty} \frac{\alpha(a')}{\sqrt{a'^2 - a^2}} da'$$

Abel transform  
 $\alpha$  – bending angle  
 $a$  – impact parameter

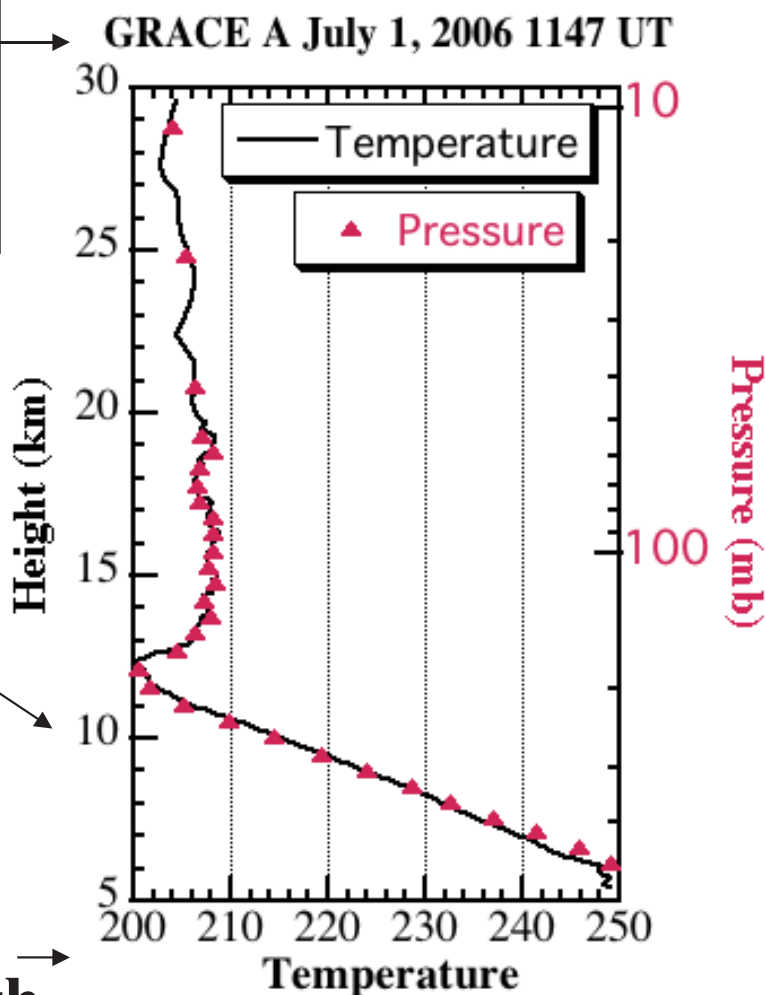


# Data Quality Issues

- Low SNR
- Abel extrapolation
- Ionospheric residual

- Lose L2 signal
- Transition closed loop to open loop (rising L2)

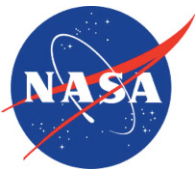
- Retrieval stops
- Atmospheric multipath
- Non-linear response



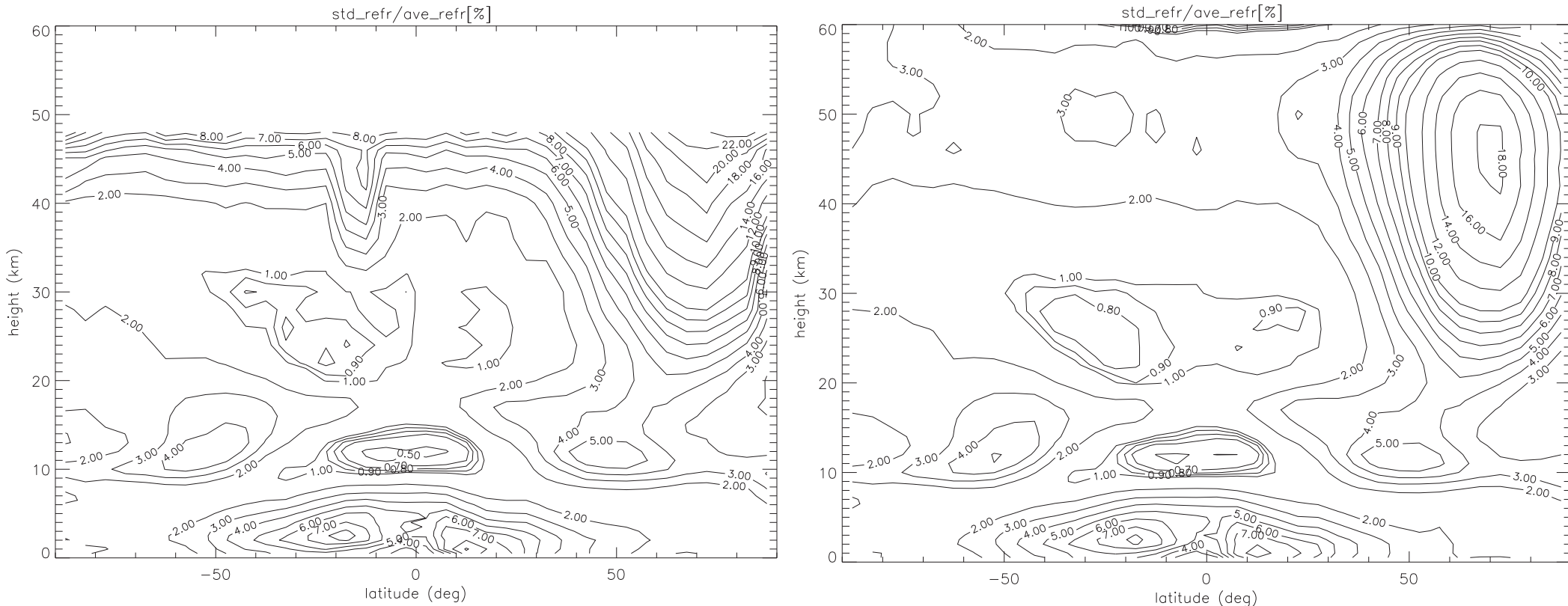
- Higher gain: digital beam steering
- Single differencing/USO clock

- Higher gain (L2)
- L2C tracking
- Offline science processing

- Higher gain
- Wider bandwidth



# Fractional Refractivity Variance



Differences found above 30 km in two approaches (JPL & UCAR)  
Higher SNR could provide more flexibility as to approach

The following reference suggests that GPS retrievals show less variance compared to SABER measurements above 35 km.

Wang, L., and M. J. Alexander (2009), Gravity wave activity during stratospheric sudden warmings in the 2007–2008 Northern Hemisphere winter, *J. Geophys. Res.*, 114, D18108, doi:10.1029/2009JD011867.